HARMONICS

Electricity generation is normally produced at constant frequencies of 50 Hz or 60 Hz and the generators' e.m.f. can be considered practically sinusoidal. However, when a source of sinusoidal voltage is applied to a nonlinear device or load, the resulting current is not perfectly sinusoidal. In the presence of system impedance this current causes a non-sinusoidal voltage drop and, therefore, produces voltage distortion at the load terminals, i.e. the latter contains harmonics.

Definition of Harmonics

Webster's New World Dictionary defines *harmonics* as pure tones making up a composite tone in music. A pure tone is a musical sound of a single frequency, and a combination of many pure tones makes up a composite sound. Sound waves are electromagnetic waves traveling through space as a periodic function of time. Can the principle behind pure music tones apply to other functions or quantities that are time dependent. In the early 1800s, French mathematician, Jean Baptiste Fourier formulated that a periodic nonsinusoidal function of a fundamental frequency *F* may be expressed as the sum of sinusoidal functions of frequencies which are multiples of the fundamental frequency. In our discussions here, we are mainly concerned with periodic functions of voltage and current due to their importance in the field of power quality. In other applications, the periodic function might refer to radiofrequency transmission, heat flow through a medium, vibrations of a mechanical structure, or the motions of a pendulum in a clock.

A sinusoidal voltage or current function that is dependent on time *t* may be represented by the following expressions

Voltage function, v(t) = V sin (ωt)

Power system harmonics are higher order frequency currents and voltages superimposed on the respective fundamental **(50** Hz **or 60** Hz) frequency waveform. They are caused primarily by non-linear loads such as arc furnaces, diode and thyristor

In the power system, the definition of a harmonic can be stated as, *a sinusoidal component of periodic wave having frequency that is an integral multiple of the fundamental frequency*. Thus for a power system with f_0 fundamental frequency, the frequency of the n^{th} order of harmonic is nf_0 Harmonics are often used to define distorted sine waves associated with *mmf fluxes*, *currents* and *voltages* of different magnitudes and frequencies.

4.2 Harmonic Distortion

Power quality is ultimately a consumer-driven issue, and the end user's point of reference takes precedence.

Any power problem manifested in voltages, current, or frequency deviations that results in failure or misoperation of customer equipment.

Harmonic distortion is caused by nonlinear devices in the power system. A nonlinear device is one in which the current is not proportional to the applied voltage. Figure 5.1 illustrates this concept by the case of a sinusoidal voltage applied to a simple nonlinear resistor in which the voltage and current vary according to the curve shown. While the applied voltage is perfectly sinusoidal, the resulting current is distorted. Increasing the voltage by a few percent may cause the current to double and take on a different wave shape. This is the source of most harmonic distortion in a power system.

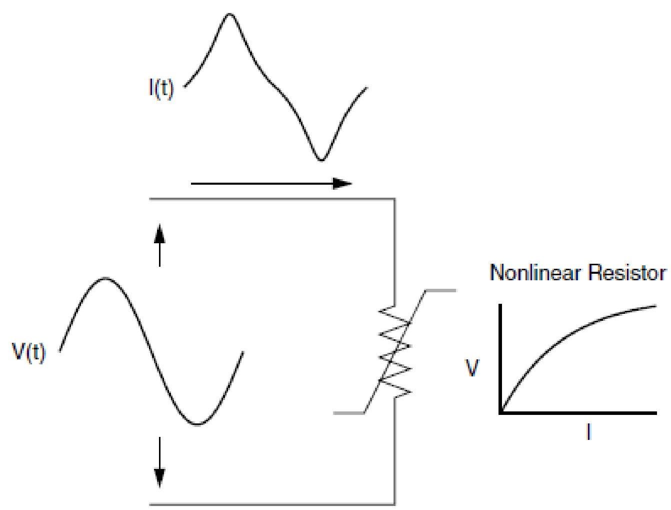

Figure 4.1 Current distortion caused by nonlinear resistance

Figure 4.1 illustrates that any periodic, distorted waveform can be expressed as a sum of sinusoids. When a waveform is identical from one cycle to the next, it can be represented as a sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave. This multiple is called a *harmonic* of the fundamental, hence the name of this subject matter. The sum of sinusoids is referred to as a *Fourier series,* named after the great mathematician who discovered the concept.

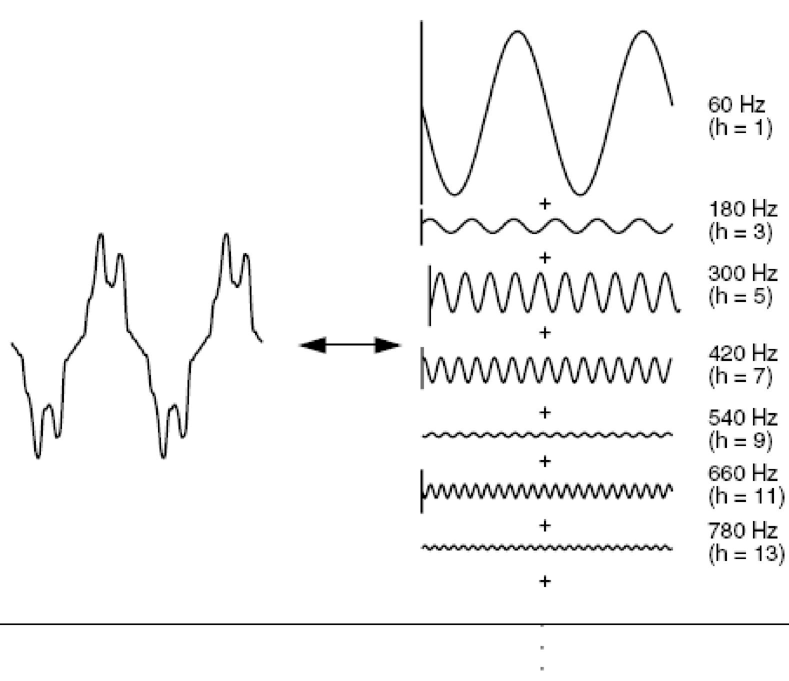

Figure 4.2 Fourier series representation of a distorted waveform

Because of the above property, the Fourier series concept is universally applied in analyzing harmonic problems. The system can now be analyzed separately at each harmonic. In addition, finding the system response of a sinusoid of each harmonic individually is much more straightforward compared to that with the entire distorted waveforms. The outputs at each frequency are then combined to form a new Fourier series, from which the output waveform may be computed.

When both the positive and negative half cycles of a waveform have identical shapes, the Fourier series contains only *odd* harmonics. This offers a further simplification for most power system studies because most common harmonic-producing devices look the same to both polarities. In fact, the presence of even harmonics is often a clue that there is something wrong either with the load equipment or with the transducer used to make the measurement.

There are notable exceptions to this such as half-wave rectifiers and arc furnaces when the arc is random. Usually, the higher-order harmonics (above the range of the 25th to 50th, depending on the system) are negligible for power system analysis. While they may cause interference with low-power electronic devices, they are usually not damaging to the power system. It is also difficult to collect sufficiently accurate data to model power systems at these frequencies. A common exception to this occurs when there are system resonances in the range
of frequencies. These resonances can be excited by notching or switching transients in electronic power converters. This causes voltage waveforms with multiple zero crossings which disrupt timing circuits. These resonances generally occur on systems with underground cable but no power factor correction capacitors.

If the power system is depicted as series and shunt elements, as is the conventional practice, the vast majority of the nonlinearities in the system are found in *shunt* elements (i.e., loads). The series impedance of the power delivery system (i.e., the short-circuit impedance between the source and the load) is remarkably linear.

In transformers, also, the source of harmonics is the shunt branch (magnetizing impedance) of the common ―T‖ model; the leakage impedance is linear. Thus, the main sources of harmonic distortion will ultimately be end-user loads. This is not to say that all end users who experience harmonic distortion will themselves have significant sources of harmonics, but that the harmonic distortion generally originates with some end-user’s load or combination of loads.

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